

# BARIUM CLOUD MODELING: PAST AND PRESENT (but not the future, yet)

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# BARIUM CLOUDS IN SPACE

outline

- ionosphere release
  - structure
  - skidding
- magnetospheric release: Hall MHD

# AVEFRIA EXPERIMENT

barium cloud release in the ionosphere

LEVEL<sup>II</sup>

AP-E 300 856



DNA 5179T

## OPTICAL MEASUREMENTS OF LASL OPERATION AVEFRIA BARIUM SHAPED CHARGE RELEASE PHENOMENOLOGY

ADA 087847

Technology International Corporation  
75 Wiggins Avenue  
Bedford, Massachusetts 01730

1 November 1979

Topical Report for Period 1 October 1978–1 October 1979

CONTRACT No. DNA 001-79-C-0032

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# BARIUM CLOUD STRUCTURE



# BARIUM CLOUD STRUCTURE

from P.A. Bernhardt

## Ave Fria Dos

Avefria Dos- This release was at Tonopah, Nevada in May 1978 (Pongrantz et al.) at an altitude of about 190 km. The view is from Hot Creek Valley, Nevada about three minutes after the release. This was a 1.45 kg shaped charged barium release fired across the magnetic field. The barium cloud had an initial radius of about 1 km. The "cats paw" part of the figure is looking up the magnetic field line, and the longer part of the cloud is not up the field line.



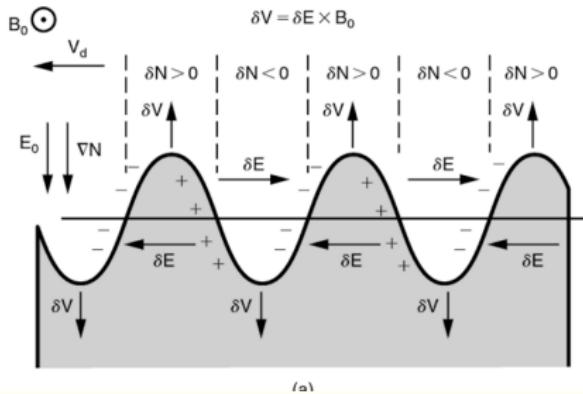
# GRADIENT DRIFT INSTABILITY

long history

- Simon, A., Instability of a partially ionized plasma in crossed electric and magnetic fields, *Phys. Fluids*, 6, 382, 1963
- Linson, L. M. and J. B. Workman, Formation of striations in ionospheric plasma clouds, *J. Geophys. Res.*, 75, 3211, 1970.
- Ossakow, S. L., P. K. Chaturvedi and J. B. Workman, High-altitude limit of the gradient drift instability, *J. Geophys. Res.*, 83, 2691, doi:10.1029/JA083iA06p02691, 1978.

# GRADIENT DRIFT INSTABILITY

physics and growth rate (from Kelley (2009))



growth rate:

$$\gamma = V/L_n \quad \text{collisional limit}$$

$$\gamma = (\nu_{in} V / L_n)^{1/2} \quad \text{collisionless limit}$$

# NUMERICAL SIMULATIONS

from McDonald et al. (1980)

$$\Sigma(x, y) = \int \sigma_p(x, y, z) dz \quad (\text{barium conductance})$$

$$\frac{\partial \Sigma}{\partial t} = -\nabla \cdot (\Sigma \mathbf{V}) \quad \text{where} \quad \mathbf{V} = -\frac{c}{B} \nabla \phi \times \mathbf{e_z}$$

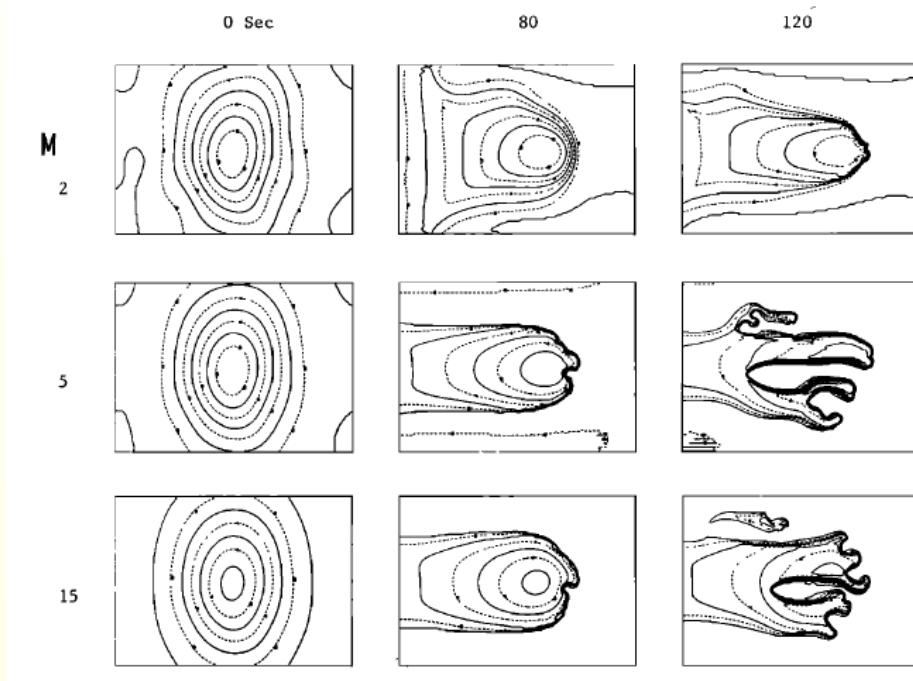
$$\nabla \cdot (\Sigma \nabla \phi) = \frac{B}{c} \mathbf{V_n} \cdot \nabla \Sigma$$

$$M = \Sigma_{max}/\Sigma \quad \text{cloud 'strength'}$$

# NUMERICAL SIMULATION RESULTS

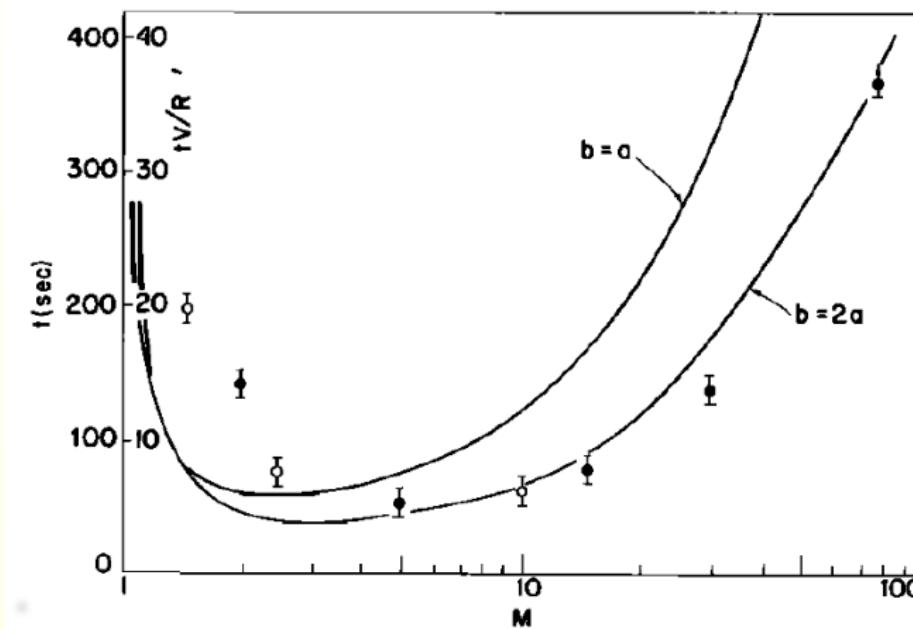
from McDonald et al. (1980)

MCDONALD ET AL.: SIMULATION OF AVEFRIA STRIATIONS



# SIMULATION VS ANALYTIC THEORY

from McDonald et al. (1980)



# BARIUM CLOUD

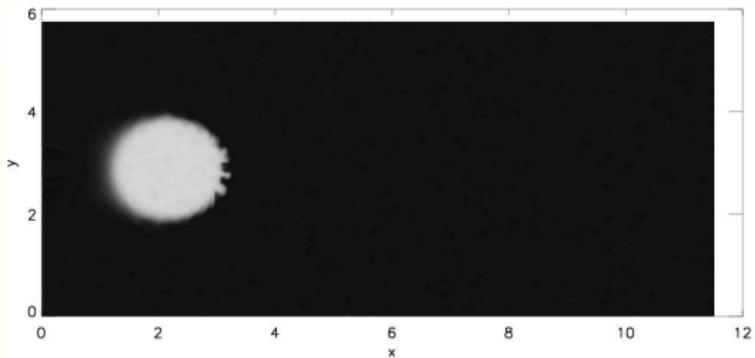
$M = 2$

# BARIUM CLOUD

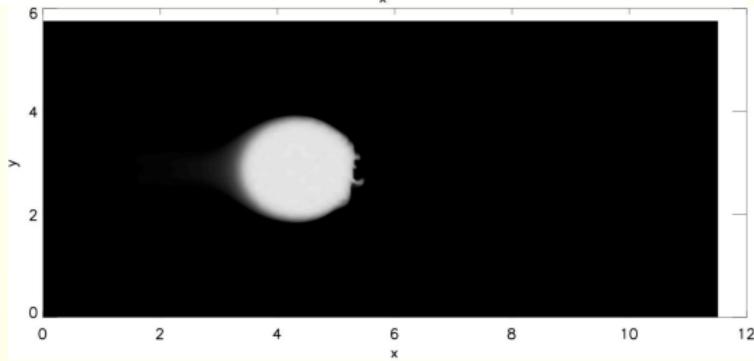
$M = 10$

# M2/M10 COMPARISON

M2 faster than M10



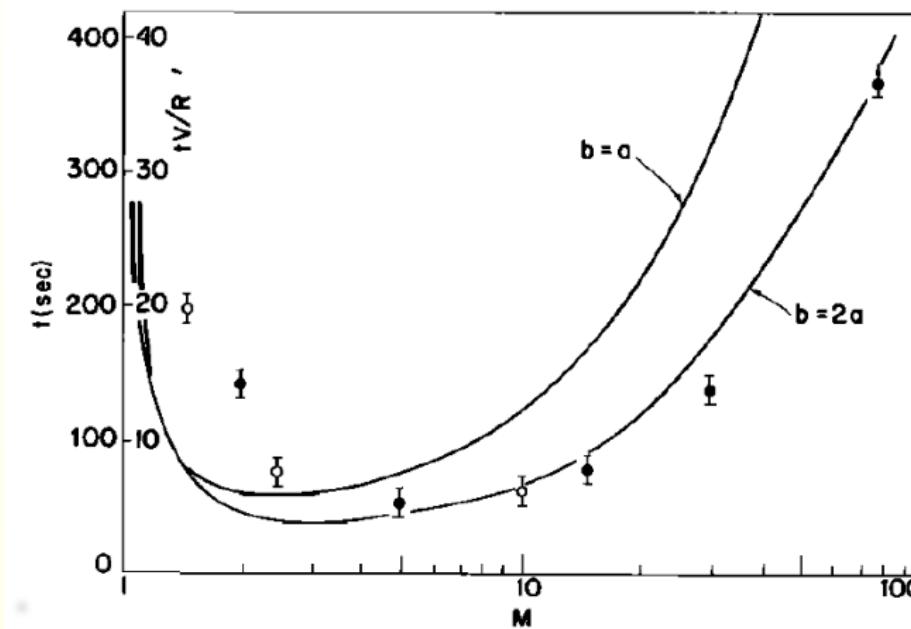
M2



M10

# SIMULATION VS ANALYTIC THEORY

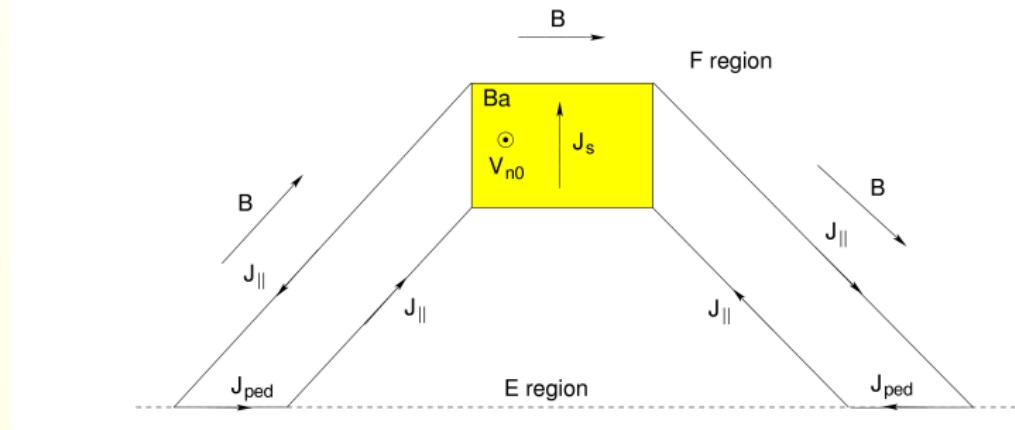
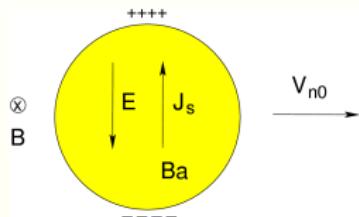
from McDonald et al. (1980)



- solve continuity, velocity, temperature equations
- ions:  $\text{H}^+$ ,  $\text{O}^+$ ,  $\text{He}^+$ ,  $\text{N}^+$ ,  $\text{N}_2^+$ ,  $\text{NO}^+$ ,  $\text{O}_2^+$   
added  $\text{Ba}^+$
- full transport for all ions
- interhemispheric model
- vertical and zonal  $E \times B$  drift  
obtained from solution of potential equation
- ambient neutral species: NRLMSISE00/HWM93
- fully parallelized (MPI)
- nonorthogonal, nonuniform fixed grid

# SCHEMATIC OF CLOUD ELECTRODYNAMICS

'skidding'



# 3D BARIUM CLOUD SIMULATION

modified version of SAMI3

- based on CRRES G-9 study (Huba et al., *GRL* 19, 1085, 1992) and ESF study (Huba et al., *GRL* 35, L010102, 2008)
- neutral barium cloud evolution

$$N_{Ba} = \frac{(1 - \epsilon) N_0 e^{-\sigma_i t}}{(\pi)^{3/2} v_{th}^3 t^3} \exp \left[ -\frac{(x - x_0 - V_{n0} t)^2 + (y - y_0)^2 + (z - z_0)^2}{v_{th}^2 t^2} \right]$$

- barium ionization rate  $\sigma_i = 0.0357$

# 3D BARIUM CLOUD SIMULATION

basic equations

- ion continuity equation

$$\frac{\partial n_i}{\partial t} + \nabla \cdot (n_i \mathbf{V}_i) = P_i - L_i n_i$$

- ion velocity equation

$$\frac{\partial \mathbf{V}_\alpha}{\partial t} + (\mathbf{V}_\alpha \cdot \nabla) \mathbf{V}_\alpha = -\frac{1}{\rho_\alpha} \nabla \mathbf{P}_\alpha + \frac{e_\alpha}{m_\alpha} \mathbf{E} + \frac{e_\alpha}{m_\alpha c} \mathbf{V}_\alpha \times \mathbf{B} + \mathbf{g}$$

$$-\nu_{\alpha n} \mathbf{V}_\alpha - \sum_j \nu_{\alpha j} (\mathbf{V}_\alpha - \mathbf{V}_j)$$

$$-\frac{\sigma_i n_n}{n_i} (\mathbf{V}_i - \mathbf{V}_{n0}) \quad \text{barium ion source}$$

# POTENTIAL EQUATION

based on current conservation:  $\nabla \cdot \mathbf{J} =$

$$\nabla \cdot (\Sigma_{Pc} + \Sigma_{Pi}) \nabla \phi = -\nabla \cdot \Sigma_{Ps} \left( \underbrace{\nabla \phi - \frac{B}{c} \mathbf{V}_{n0} \times \mathbf{e}_z}_{J_s} \right)$$

$$\Sigma_{Pi} = \int \sum_j (ce/B)(n_j \nu_{jn}/\Omega_j) dz$$

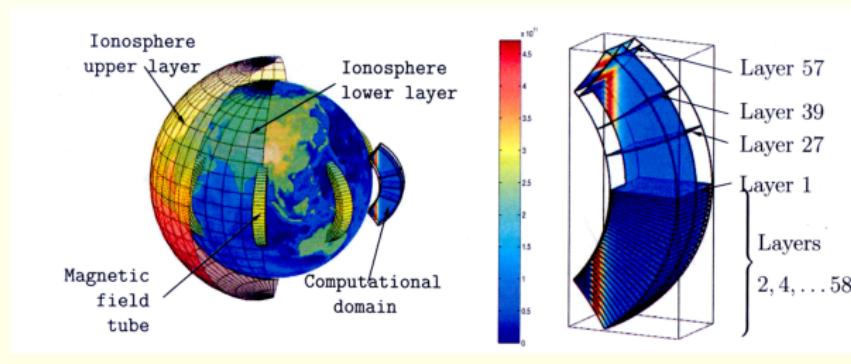
$$\Sigma_{Pc} = \int (ce/B)(n_c \nu_{cn}/\Omega_c) dz$$

$$\Sigma_{Ps} = \int (ce/B)(n_n \sigma_i/\Omega_c) dz$$

- $i$ : background ionosphere
- $c$ : barium ion cloud

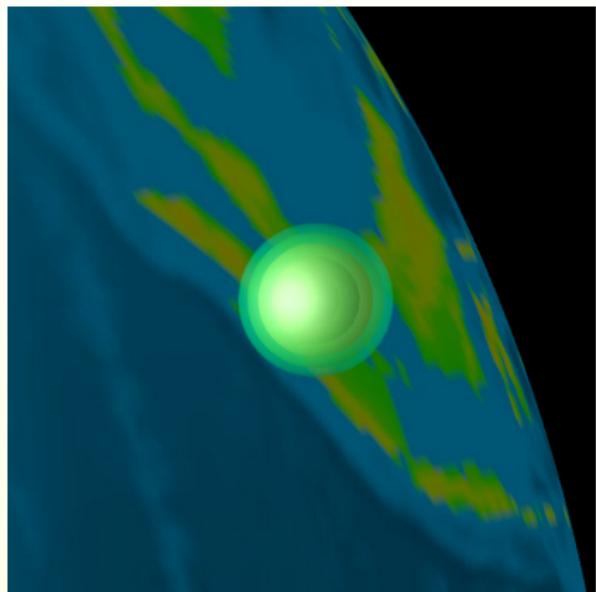
# SIMULATION PARAMETERS

- $N_{Ba} = 10^{27}$  (barium neutrals)
- $V_{n0} = 10$  km/s (injection velocity)
- $v_{th} = 1.5$  km/s (expansion velocity)
- $F10.7 = 170$  (solar flux)
- LT = 0630 (morning)
- $t_0 = 80$  s (1 min run time)
- geometry: longitudinal wedge  $12^\circ$  ( $L = 1380$  km)

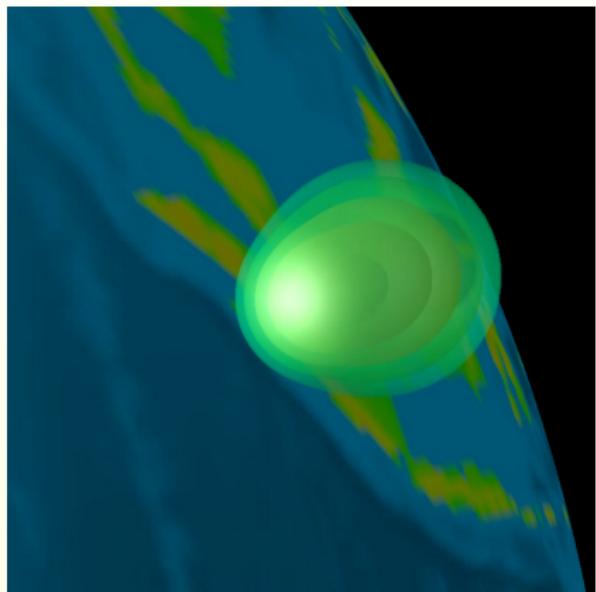


# RESULTS 1

barium ion isosurfaces



$t = 0$  s



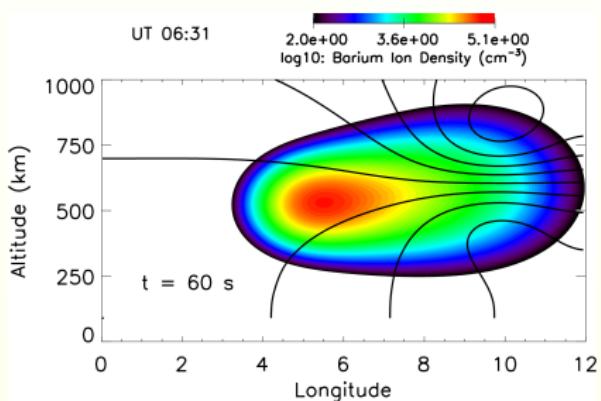
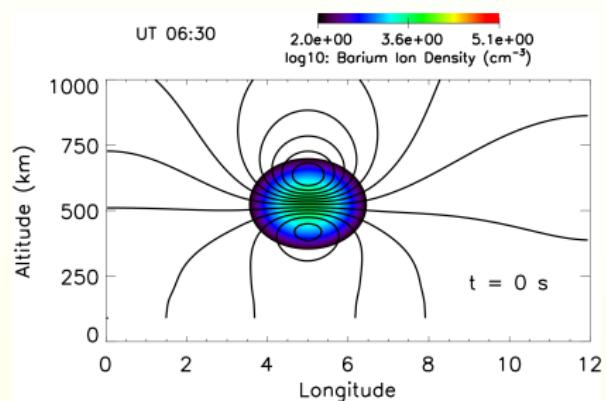
$t = 46$  s

# RESULTS 1

barium ion isosurfaces

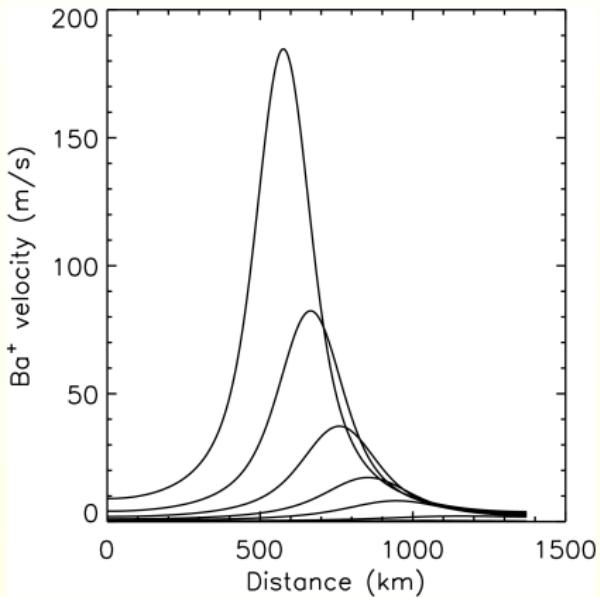
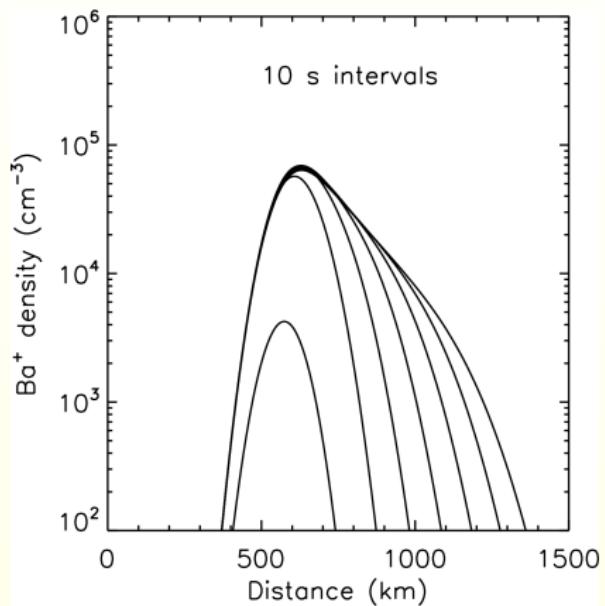
# RESULTS 2

density and potential contours



# RESULTS 3

density and velocity plots



- skidding

- maximum  $E \times B$  velocity:  $V_{skid} \simeq 200$  m/s, i.e., very little skidding
- velocity scales as

$$V_{skid} \simeq \frac{\Sigma_{ps}}{\Sigma_{pb} + \Sigma_{pc} + \Sigma_{ps}} V_{n0} \simeq 0.05 V_{n0} \simeq 500 \text{ m/s}$$

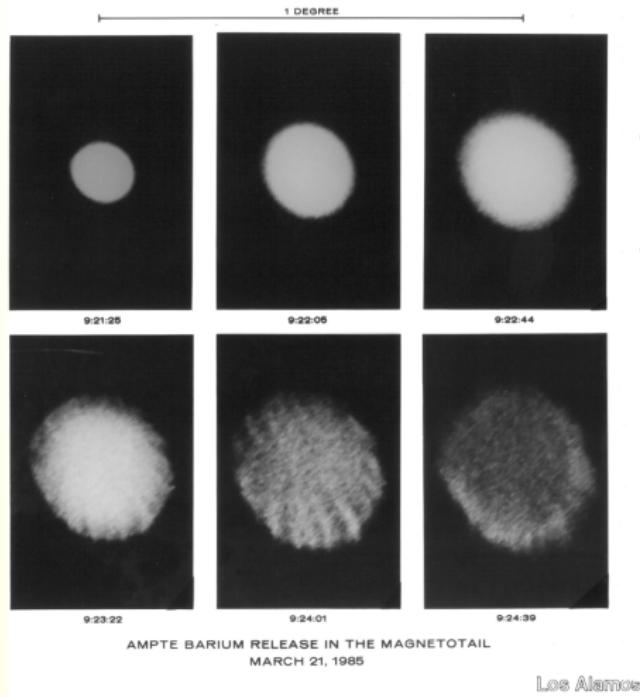
- energy loss:  $(1/2)M_{Ba}V_{skid}^2 \simeq 5 \text{ MJ}$

- Alfvén wave propagation

- Alfvén velocity:  $V_A \simeq 10^3 \text{ km/s}$
- field line length to  $E$  region:  $L \simeq 3 \times 10^3 \text{ km}$
- transit time:  $\simeq 3 \text{ s} \ll 30 \text{ s}$  (ionization time)
- assume complete coupling to  $E$  region

# HALL MHD: SUB-ALFVÉNIC EXPANSIONS

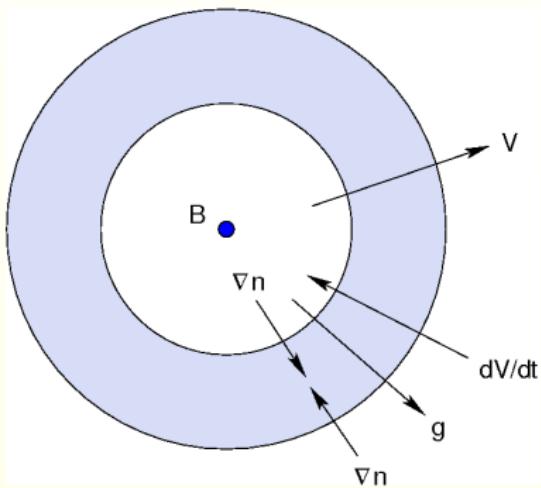
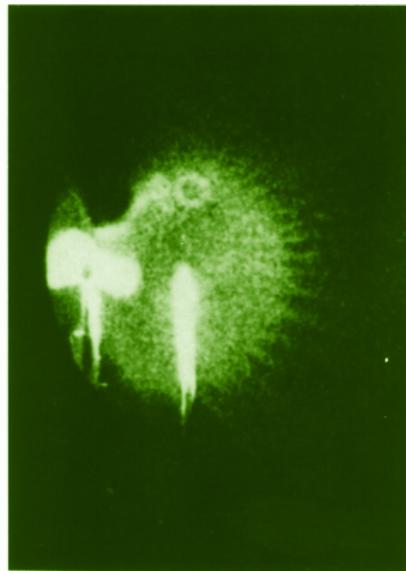
magnetospheric barium releases (*Bernhardt et al., JGR, 1987*)



- rapid structure formation:  
 $t < \Omega_i^{-1}$
- small scale structure:  
 $\lambda < \rho_i$

# HALL MHD: SUB-ALFVÉNIC EXPANSIONS

laser-plasma interaction (*Ripin et al., PRL, 1987*)



# HALL MHD: SUB-ALFVÉNIC EXPANSIONS

theory (Hassam and Huba, GRL, 1987)

- dispersion equation

$$\omega^4/k^2 V_A^2 - (1 + \beta)\omega^2 +$$

$$(g/L_n)(1 - \partial \ln B / \partial \ln n) -$$

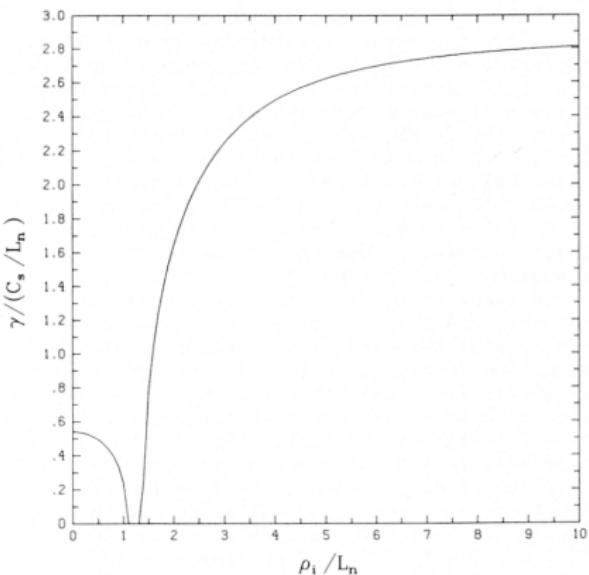
$$(\rho_i/L_n)(\omega^2 - k^2 g L_n) (\omega/k C_s) = 0$$

where  $g = -dV_0/dt$

- limiting cases for the growth rate:

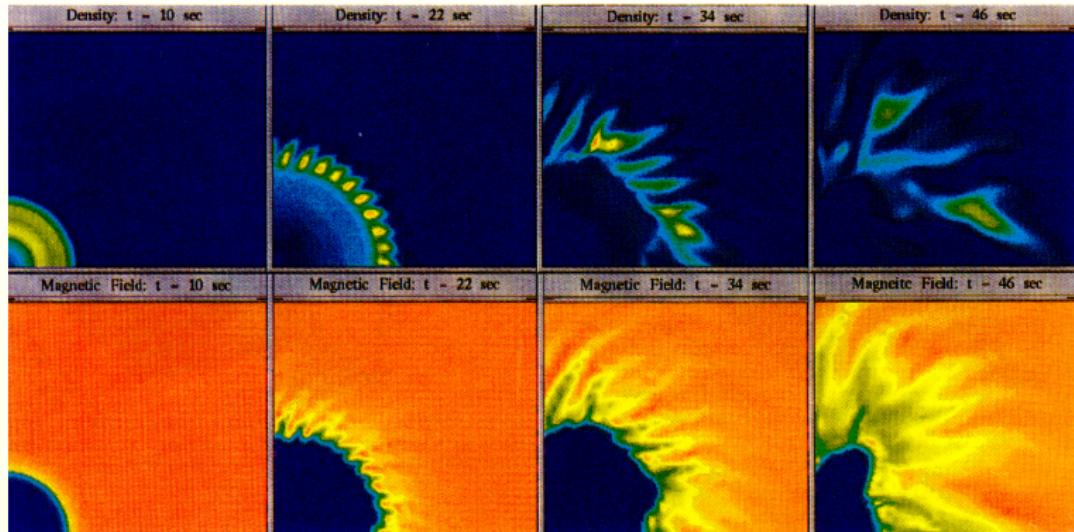
$$\gamma = (g/L_n)^{1/2} \quad \rho_i \ll L_n$$

$$\gamma = k L_n (g/L_n)^{1/2} \quad \rho_i \gg L_n$$



# HALL MHD: SUB-ALFVÉNIC EXPANSIONS

simulation study (*Huba et al., JGR, 1992*)



# HALL MHD: SUB-ALFVÉNIC EXPANSIONS

psychedelic perspective

